BULLETIN NO. 638 JANUARY, 1934

New York State Agricultural Experiment Station

Geneva, N. Y.

CROWN GALL AND HAIRY ROOT OF APPLES IN NURSERY AND ORCHARD

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PUBLISHED BY THE STATION
UNDER AUTHORITY OF CORNELL UNIVERSITY

ABSTRACT

In New York, nursery stock is now propagated by budding. It has been found by experience that the heavy losses due to crown gall and overgrowths accompanying grafting can thus be avoided. By the use of budded stock it has been found that New York fields are mostly free from the crown gall organism. The small percentage of gall present in such fields can be traced to pruning wounds made prior to setting of the seedlings.

Budded apple trees may be badly diseased with crown gall when grown in fields heavily infected by the previous nursery crop such as grape, peach, raspberry, rose, etc. No varietal differences in susceptibility to crown gall could be observed when budded stock was grown on an infected field. In the same field greater infection was observed on heavy clay soils than on loam. Inoculations made on orchard trees have shown that the organism may be latent and not show any visible signs of gall formation until the third growing season.

Normal, crown gall, and hairy root trees have been planted in an orchard and the differences of growth determined by measuring the diameter of the trunk. The results were not uniform for all the varieties tested. Wealthy trees infected with hairy root showed the smallest trees of any group, while the McIntosh trees were as good as the checks. Baldwin, McIntosh, and Wealthy trees badly galled were on the average smaller than the checks. The galls observed at the time of setting proved to be of the hard type and were still present and had increased in size when examined after 8 years. Both hairy root and crown gall tended to produce a one-sided root system.

The practical phases of the results can be applied by the orchardist, nurseryman, and nursery inspector. An acquaintance with the signs and intergradations in crown gall and hairy root, as well as a knowledge of the variations occurring in the root systems of normal trees, will greatly aid in establishing uniformity in the inspection of trees shipped to the different states and provinces.

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INTRODUCTION

Ever since the infectious nature of crown gall became known, there has been a difference of opinion as to the advisability of setting apple trees with root malformations. Often the opinion has been influenced by the viewpoint of the individual according as he happened to be the purchaser or the seller of such trees. Ultimately, a controversy arose between the nurserymen, on the one hand, and orchardists, horticulturists, nursery inspectors, and plant pathologists, on the other, as to the injurious nature of the malformations involved. Much contradictory evidence has been presented.

At the convention of the American Association of Nurserymen held in Denver in 1910, Smith (9) [1] and others cited cases where galled trees have apparently produced just as good orchards as did normal trees. However, Hedgcock (5), Back (1), Swingle and Morris (13), Greene and Melhus (3), and others, believe that the presence of the gall is injurious to the growth of the apple tree. Stewart, Rolfs, and Hall (11) found crown gall common on apple trees in New York nurseries, but knew of no case where it caused material loss.

Reddick and Stewart (8), however, could not detect from their appearance, size, and length that there was any difference between the roots of galled trees and those free from gall. In their limited test, consisting of 29 diseased and 7 check trees, they set out eight varieties of 2-year budded trees on French seedlings. Except for the presence of the gall, the trees would have been graded as of the best quality. When removed after 9 years, there was not the least indication that the gall-free trees pulled more easily than those originally bearing galls. In many instances the original galls had entirely disappeared. This was true in practically all cases where the tree had a long rootstock with the gall located near its base.

[1] Refers to Literature Cited, page 30.

At the request of nurserymen, the subject of crown gall and its inspection was again considered by nurserymen, nursery inspectors, horticulturists, and plant pathologists in a symposium held at the conventions assembled in Cincinnati (2) in 1923. In the report (10) adopted at that time the opinion was expressed that, "In general, the injurious effects of crown gall have been overestimated, particularly in the case of the apple. Crown gall injury is least pronounced in the northern and northeastern portions of the United States."

As the result of this conference some of the practical phases of the importance of crown gall and hairy root were investigated by this Station. Information was desired on the following questions: 1. What effect have these diseases on the growth of young apple trees? 2. What is their effect on growth, age of bearing, yields, ability to withstand heavy winds, and disease resistance of mature trees?

After growing diseased and normal trees for 8 years, it is believed that the first question can now be answered. After another 10 years of observations, it is hoped that light will be shed on the second question.

At the outset of this investigation the writer held the opinion that crown gall was not injurious to the future growth of the apple tree. This viewpoint has been altered, however, since, in the light of the present investigation, it has become evident that the final results of the experiment depended greatly upon the selection of the material used at the outset of the test. It also became evident that factors other than root malformations may exert an influence greater than the mere presence or absence of the disease. In this investigation various types of diseased roots were sorted out and described so that eventually the effect could be properly evaluated and the injurious results established. If it can be shown here that malformations on the roots may interfere with the production of a normal tree, then the orchardist must be given the benefit of any doubt and the State, thru its inspection service, should protect the grower by preventing the sale of such diseased trees within its borders.

AMOUNT OF DISEASE ON NURSERY STOCK

The amount of crown gall observed on apple nursery stock in New York is much less than was found a decade ago. In 1923, a block of 723 Cortland grafts was dug on the Station grounds and

28.8 per cent showed galls 0.75 inch or larger in diameter; 28.7 per cent showed flat galls with hairy root and the remainder showed traces of gall, overgrowths, and hairy root. Budded Cortland trees growing alongside of this block showed neither gall nor hairy root. Grafting has been almost entirely replaced by budding so that now crown gall is found in New York only in traces, unless exceptional conditions prevail.

Hedgcock (5) usually found less gall on budded stock than on grafted trees. He reported two exceptions, one from Utah and another from Virginia, where budded trees were badly diseased with crown gall. It was assumed that the organism causing the gall formation was widely distributed and present in all soils. This was based mostly on the observation that grafts planted in any soil showed a high percentage of gall. Nevertheless, it is necessary to note the behavior of budded stock on infected and non-infected soil.

Hedgcock (5) found in seedling nurseries less than 0.5 per cent of crown gall of the soft type and about 1 per cent of hairy root. On non-infected land the writer found similar amounts on 2-year-budded trees. In 1925, 3263 representative trees of a large block of different varieties of apples were counted at digging time and only 2 were found that showed the gall. In these trees the gall was at the basal end of the rootstock where the French seedling had been trimmed. In the McIntosh and Cortland varieties in different rows there was a variation in the amount of hairy root from 7.6 to 20.3 per cent and an average of 14.78 per cent.

Tukey and Brase (14) have shown the results of the interrelation of the cion and the rootstock and the rôle each may play in determining the top growth as well as the characteristic growth of the root systems.

The writer observed that on heavy soil the Duchess of Oldenburg, Wealthy, Crab, and Double Flowering Crab tended to produce finger-like roots that grew downward. The Winter Banana, Stark, and Northwestern Greening, under similar conditions, tended to produce fibrous roots which grew more in a horizontal direction. The Cortland and McIntosh formed roots intermediate to these contrasting types.

The growth of nursery stock on land heavily infected with the crown gall organism may cause heavy losses to the nurseryman. Such losses have been reported where apple trees have followed

infected peaches, raspberries, grapes, roses, etc. In 1933, the writer had an opportunity to observe a block of 65,000 2-year-old budded apple trees that were ruined for sale because of crown gall. The history of this unusual field is as follows: In 1929, a large field was planted with *Rosa odorata* received from California and from which all plants showing crown gall and nematode nodules were apparently removed. They were budded that same year and when dug in 1930 showed considerable gall present. In 1931, the field was planted with seedlings of pear, cherry, plum, and apple. At the time of digging (October 30 to 31, 1933) careful counts were made of the amount of gall present. Of the 25,000 cherry trees of different varieties on Mazzard stock 2 per cent showed hairy root and 1.5 per cent showed crown gall. In the block of 20,000 cherry trees on Mahaleb stock, no gall nor hairy root was found. In the block of 15,000 plums on Myrobalan stock, only 3 trees showed a malformation at the basal end of the rootstock which was considered as gall. The pears on French stock and the apples on seedlings grown in Washington displayed a large amount of gall present as shown in Tables 1 and 2. The apples had made an excellent top growth, but the roots were festooned with soft galls varying in size from a pin head to 3 inches in diameter (Fig. 1). Some of the galls were 2

FIG. 1.—GALLS VARYING IN SIZE FROM A PIN HEAD TO 3 INCHES IN DIAMETER. On 2-year-budded McIntosh grown on infected soil.

years old and had begun to disintegrate, while others were newly formed. It was found that the percentage of infection was about the same in all varieties, but the degree of infection varied in different portions of the land. The large field was comparatively flat at the ends and at about two-thirds of its length there was a sudden

TABLE 1.— AMOUNT OF CROWN GALL ON 2-YEAR-OLD BUDDED APPLE TREES.*

VARIETY	PERCENTAGE OF INFECTION				PERCENTAGE OF UNSALABLE TREES		
	Average	On the flat	Base of knoll	On the knoll	On the flat	Base of knoll	On the knoll
On Infected Soil, 65,000 Trees							
Cortland	97	....	....	....	....	....	.....
Baldwin	95	....	....	....	....	....	.....
Delicious	99	....	....	....	....	....	.....
Early Harvest	98	....	....	....	....	....	.....
Gravenstein	97	....	....	....	39	....	.....
Duchess of Oldenburg	100	....	....	....	....	54	.....
Fameuse	100	....	....	....	....	....	76
Grimes	99	....	....	....	....	42	.....
Hubbardston	98	100	96	....	42	51	.....
Hyslop	99	....	98	100	....	38	71
Tompkins King	95	89	....	97	12	....	72
McIntosh	96	92	97	96	24	55	79
Red Astrachan	98	96	100	99	44	35	74
Rhode Island Greening	90	73	97	99	29	30	64
Roxbury Russet	99	97	99	100	23	48	74
Stayman Winesap	96	94	93	100	27	56	71
On Non-infected Soil, 15,000 Trees							
Sweet Bough	1.00						
Tolman Sweet	0.00						
Wagener	0.00						
Wealthy	0.00						
Wolf River	0.00						
Winter Banana	0.00						
Yellow Transparent	0.68	(3,500 trees examined)					
Jonathan	1.06	(1,600 trees examined)					
Rome Beauty	3.18	(1,500 trees examined)					

* Data compiled with assistance of nursery inspectors B. Blanch and H. Breitfeld.

TABLE 2.— AMOUNT OF CROWN GALL ON 21,000 2-YEAR-OLD BUDDED PEARS GROWN ON INFECTED SOIL.*

VARIETY	PERCENTAGE OF INFECTION	PERCENTAGE OF UNSALABLE TREES
Seckel	52	16
Kieffer	51	15
Bartlett	98	53
Beurré Bosc	79	26
Beurré d'Anjou	92	49
Flemish Beauty	75	15
Clapp Favorite	71	17

* Data compiled with assistance of nursery inspectors B. Blanch and H. Breitfeld.

rise of about 15 feet which formed a well-rounded knoll of clay soil. On the flat portions of the field the soil was of a loam type. The degree of infection was highest on the heavy clay knoll from which the water drained toward the flats.

Where the seedling stock was planted on an adjoining field with a similar topography, the results were entirely different where the soil was not infected. These data are given in Table 1. It will be observed that only traces of gall could be found. The galls observed were localized and followed a definite depression in the land. It was unknown just what ornamental shrub had been planted on this exact spot in previous years. Hedgcock (5) found Wealthy, Yellow Transparent, and Wolf River the most susceptible to crown gall when whip grafts were planted. He concluded that different varieties showed a wide variation in their susceptibility toward gall. These varieties as observed by the writer when on budded stock and on non-infected soil remained free from gall.

Counts were not made of the trees showing hairy root since little was present in the entire planting. It was observed that the Yellow Transparent apple and the Abundance plum produced a vigorous top growth which was associated with the production of numerous fibrous rootlets on the horizontal roots growing near the surface of the ground. Those penetrating deeper into the clay subsoil were devoid of such fine rootlets. Trees with an excessive number of fibrous rootlets often have been rejected by nursery inspectors of some states since it was believed they were cases of hairy root.

CAUSES OF MALFORMATIONS ON APPLE ROOTS

The diagnosis of the malformations on apple nursery stock may be uncertain since it is difficult to determine accurately in the field the various types involved. Intergradations of one form to another can readily be found, indicating that the crown gall and the hairy root organism may be present either singly or mixed. Disregarding root enlargements induced by woolly aphis and nematodes, the malformations may be placed in two main groups, namely, the infectious and the non-infectious types.

CROWN GALL

Crown gall is the name given to an excresence either on the root, graft union, or trunk of nursery stock induced by the organism *Phytomonas tumefaciens*. The organism usually gains entrance

thru the wound made during the grafting process and its presence stimulates the abnormal growth or gall. On budded stock the manner in which infection takes place is not always clear. It is possible that the organism gains entrance either thru ruptures made in the cortex by the emerging rootlets or is introduced by some carrier. Two types of galls are formed, namely, the soft gall and the hard gall. Both develop in the same manner, but the latter becomes covered with bark and continues its growth for years. According to Hedgcock (5), the soft galls disintegrate at the end of the growing season.

Non-infectious overgrowths or excessive callus formation at the graft union may be mistaken for crown gall. They may disappear while in other cases they may harbor the gall organism and continue to enlarge so as to girdle the tree. Where the overgrowth can not be distinguished from crown gall, it is necessary for practical purposes to reject affected trees and consider them as culls.

HAIRY ROOT

Hairy root is recognized by the production of fleshy roots found either singly or in clusters at the base of the trunk, crown, and roots. The infectious type is induced by the organism *Phytomonas rhizogenes*. It is often associated with crown gall so that nursery trees may display a mass of fleshy roots arising from a galled surface.

BURR KNOT

Apple trees over 6 years of age may show gall-like enlargements on the trunks and branches which closely resemble crown gall but are now considered as non-infectious burr knots (Figs. 2 and 3). These contain buds from which rootlets may be produced during prolonged rains and also by wrapping wet sphagnum about the

FIG. 2.—A GALL-LIKE FORMATION OF THE BURR KNOT TYPE INDUCED ON WEALTHY TREES BY THE APPLICATION OF ASPHALTUM PAINT FOLLOWING RABBIT INJURY.
Reduced 1/3.

knots. In late winter they can be induced to form rootlets by placing the ends of removed branches in water and storing in a damp chamber.

Burr knots are sometimes considered as a varietal characteristic. Merrill and Maney (7) have noted their occurrence in crosses, and on the Station seedlings grown on their own roots they appear to be common. Crosses in which Northern Spy happens to be one of the parents showed the knot to a high degree. In 1923, 20 seedlings (Canada Red X Delicious) out of 120 trees showed the aerial type of burr knot especially on the trunks. Some were newly formed, while others were several years old and 3 to 4 inches in diameter. One knot was in the center of a canker (*Sphaeropsis malorum*) 10 inches long. The 13-year-old knotted trees when compared with the normal showed differences in growth varying from distinct dwarfing to normal. They were removed by means of a tractor and an examination of the roots showed no galls present. Instead, the trees showed varying degrees of hairy root. In some the root system was stocky and normal, while in others it was much undersized. Fleshy roots were also found on trees which showed no aerial burr knot.

FIG. 3.—A ROCKLAND TOP GRAFTED IN 1902 AND PHOTOGRAPHED APRIL, 1914.

It shows the burr knot on the trunk and branches. Subsequently the branch to the left was broken off by the wind.

In some instances the burr knots may be so numerous as to stunt the growth of the trees. Fig. 3 is from a photograph taken in 1914 of the Rockland variety top grafted in 1902. The tree made a poor growth and had to be cut back repeatedly. In later years the branch to the left was broken off near the trunk where a large burr knot had formed cross-grained wood which could not withstand heavy winds. It is evident that, while many trees

may show an apparent injury caused by the presence of burr knots, nevertheless instances can be found where their presence has resulted in stunting and weakening the tree.

The ease with which roots are produced from burr knots has been used by Swingle (12), Hatton (4), Maney (6), and others as a means of vegetative propagation of apple trees. Some of the burr knot types are utilized for grafting to form dwarf stock, but burr knot is not necessarily associated with dwarf stock since it is also found on the standard trees. In a block of nursery stock one can find a continuous variation with large stout roots at one extreme and trees with numerous fleshy roots at the other. In severe cases the condition no doubt is hairy root, while in border types it is difficult to state positively whether the tree shows a light infection of hairy root or a root type of burr knot. Because of intergradations of these types, some investigators have gone to the extreme and considered all fibrous roots as belonging to either one or the other class without considering that both may be involved. Inspectors encountering this situation must exercise considerable tolerance in their judgment and base their decisions on the general appearance of the entire root system.

CROWN GALL INOCULATIONS

To understand what responses may be going on beneath the surface of the ground, inoculations were made on sterilized roots, crown, trunk, and twigs of dormant and growing French seedlings and on Ben Davis trees in the orchard. The strain of *Phytomonas tumefaciens* used had been isolated by J. S. Muncie of Ames, Iowa, who proved its pathogenicity on Bonny Best tomato. A 2-mm sterilized drill was used to make the wound that extended into the woody tissue. After the inoculum was inserted, the wound was sealed by means of grafting wax which in turn was covered with a coat of shellac. A sterile scalpel was used to make the wounds on the small twigs. Seedlings grown in the greenhouse were inoculated February 26, 1926, when in a dormant condition and again April 19 when newly formed twigs were 6 to 8 inches long. No galls formed until autumn and not until after November 18 when the leaves were removed. The galls gradually increased in size up to Christmas when they attained their maximum size of 0.5 inch in diameter.

Sets of 51 inoculations were made on 10-year-old Ben Davis trees on April 22 when the apical buds were swelling and again on

FIG. 4.—A BRANCH OF A BEN DAVIS TREE INOCULATED APRIL 22, 1926, WITH THE CROWN GALL ORGANISM. The bark at the centers of the galls has disintegrated. Photographed December, 1933, and reduced 1/6.

May 24, 1926, when the trees were beginning to bloom. After harvest, during the autumnal period of host susceptibility about the time of leaf fall, the organism induced the initial steps of gall formation as indicated by a definite increase in size of the callus tissue. From the middle of June to the middle of July, 1927, there was a definite enlargement of the galls; the largest being 1¾ inches in diameter. In 1928, some of the inoculations which previously showed no signs of activity produced normal galls, especially on the trunk and the largest branches. A set of inoculations made March 11, 1927, showed the first tendency toward gall formation September 21, 1927, and definite galls formed in 1928 and 1929. The galls have continued their growth to the present time and some are shown in Fig. 4. The results of these inoculations may be briefly summarized as follows:

1. Typical crown galls have been induced by the introduction of the crown gall organism *Phytomonas tumefaciens*.
2. No tendency was found to produce new galls and islands of new infection except at the point of inoculation.
3. The crown gall organism may be latent in the callus tissue and not induce a visible gall formation until the second or even the third growing season.

4. The galls formed were not of the burr knot type.
5. The galls were still active 8 years after the inoculations were made.
6. The old galled tissue may be sloughed away by the formation of new tissue, either beneath the old gall or at the margins of the gall.
7. Some galls showed a disintegration of the centers of the lesion after their third year of enlargement and permitted the entrance of insects and secondary fungi, especially *Sphaeropsis malorum*.

AN ORCHARD EXPERIMENT

The object of this investigation is to test the effect of crown gall and hairy root on the health, growth, time of fruiting, and yield of infected trees under New York conditions. Baldwin, Wealthy, and McIntosh were tested since these were considered as the three important varieties grown in the State. Trees badly and moderately galled, hairy root, and check trees were planted April 28 and 30, 1925.

PLAN OF EXPERIMENT

The orchard site, a plat of land 140 by 760 feet, was formerly occupied by a Baldwin orchard from which trees 12 to 20 inches in diameter had been removed 2 years previously. The land slopes to the south gradually with a fall of about 20 feet in the distance of 760 feet. The upper 16 inches of soil is Ontario clay loam with a pH of about 7. It is tile drained and has a clay subsoil. From the behavior of the previous orchard and others nearby, the land appears to be desirable for the culture of apple trees.

The orchard was planned to consist of 12 rows running north and south with trees 10 feet apart in both directions. Row 1 is bordered on the west by a 10-year-old Ben Davis orchard. Rows 1 to 4 are Baldwin; rows 5 to 8, Wealthy; and rows 9 to 12, McIntosh. Rows 1 to 3 contain 28 trees each, while the remaining rows contain 39 trees each. Rows 2, 6, and 10 were planted with moderately galled trees. The other rows consist of a staggered mixture of diseased and check trees. As soon as the trees began to crowd, it was planned to remove part of them so that those remaining would stand 20 feet apart instead of the original 10 feet. Later, another thinning will be made, leaving only the permanent trees which will stand 40 feet apart.

PLANTING THE TREES

The trees were placed in holes which went down to the clay subsoil, or a depth of about 16 inches. They were placed so that the

gall was toward the south. This was done to determine what effect, if any, winter injury may have on the subsequent growth of the tree. The roots were given the normal pruning, but no attempt was made to remove any of the galls or hairy roots. The trees set were trimmed so as to have five main branches, but in some cases this was impossible since often such a number were lacking. The diameter of the tree 1 foot from the ground was measured and recorded.

CHOICE OF TREES

The writer at first believed it possible at any time to go into the nursery while lifting the trees and readily obtain suitable specimens of the desired varieties. This view was changed after the writer had followed a tree digger for 2 days and obtained only a few galled trees. This was due to the fact that the budded trees showed only a fraction of 1 per cent of gall infection. Specimens of 3-year-old western grafts showing the hard type of crown gall were finally obtained. During the first year the whip was cut back so as to produce a strong leader. From their appearance such trees closely resembled budded stock, but a longitudinal section showed the presence of the graft. Hence the rootstocks were 3 years old and the tops but 2 years.

Before planting, each tree was carefully described and a diagram made of the position of the gall, its size, and its relation to the stock and to the secondary roots. The presence of hairy root and the size of the main roots were also recorded. The following observations were made of the trees:

1. The height and diameter of a tree was not always correlated with the presence or absence of diseased roots.
2. The checks, or the gall-free trees, showed the formation of stout roots which were well distributed.
3. A tree showing gall invariably also showed a decrease in the diameter of the roots measured 2 inches from their origin.
4. The height and trunk diameter of diseased trees did not decrease in proportion to the decreased size of their roots.
5. Badly stunted roots may show a corresponding decrease in height and diameter of the trunk.
6. Trees badly infected with hairy root showed a dwarfing of the top growth.
7. The hairy roots arising from the stock of the tree were associated with the production of a more or less gall-like swelling. Taken as a whole, the McIntosh variety showed smaller galls than either the Baldwin or the Wealthy. The normal Wealthy and Baldwin

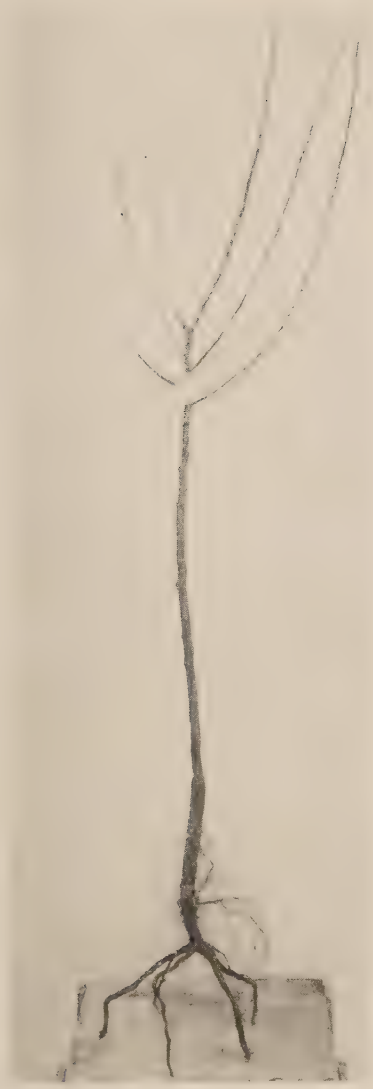

FIG. 5.—A TYPICAL 2-YEAR-OLD BALDWIN FREE FROM GALL.

FIG. 6.—A TYPICAL 2-YEAR-OLD BALDWIN CLASSIFIED AS BADLY GALLED.

trees showed a greater tendency toward the production of stout well-formed roots than did the McIntosh. On the latter variety there was a tendency for the stock to produce more fibrous feeding roots than could be found on the other two.

FIG. 7.—A TYPICAL 2-YEAR-OLD BALDWIN SHOWING HAIRY ROOTS.

SORTING OF TREES

The trees of each variety were sorted into four classes, *viz.*, hairy root, badly galled, moderately galled, and free from gall (Figs. 5, 6, and 7). The following method was employed in the further selection of the trees in order to obtain comparable material: First, the trees were selected for the permanent orchard to be set 40 feet apart. The checks and the trees having the largest galls or hairy root with the best top growth and the best root systems were planted first. Next the trees set 20 feet apart which would be removed at some future date were selected. These were not of as high a quality as the first group when the root system was considered. Lastly, were selected those trees set out 10 feet apart and which were removed April 10, 1933. The latter were of the same caliper and height as the permanent trees but lacked the well-developed root system found in the trees which were to stand 40 and 20 feet apart.

Great difficulty arose when the trees infected with hairy root were sorted. None of

the trees examined showed a hairy root condition without showing also some swelling or flat gall formation from which the fleshy roots arose. In some cases roots would arise from the galls, while in others the galls were free from roots. Apparently the infection present on this lot of trees was a mixture of the hairy root and the crown gall organisms. Usually, the galls near the crown were free from roots, while those lower on the stock produced roots. Before planting photographs were taken of typical trees utilized in this test. In all, 18 photographs were taken and they resemble similar photographs taken by Back (1), Chase (2), and others.

COMPARABLE TREES

In the light of the present investigation, it is now evident that the final result of any experiment attempting to determine the injurious nature of hard and soft crown gall and hairy root of apple trees is dependent upon the nature of the diseased material selected at the outset of the test. The variation in the final conclusions of previous investigators who have studied this problem may be explained by the variable nature of the material which the particular investigator happened to encounter. The trees utilized by one investigator may not be comparable to those of another. For instance, one may be dealing with the soft gall type of infection, while another may encounter only the hard type of gall. At the outset the writer attempted to have comparable trees in the lots to be removed at different periods. It is now doubtful if these are as comparable as was thought to be the case.

Among the permanent trees, whether checks or diseased, it may be expected that those having the best root systems at planting time will make a better top growth than trees similarly diseased but with poorer root systems. The diseased trees selected to stand permanently had root systems similar to those of the check trees, tho it is doubtful if they were strictly comparable to them since the diseased trees had made good roots in spite of the presence of disease. It is possible that a diseased tree may later manifest a degree of vigor greater than that shown by check trees because some other factors may influence the future growth of the trees more than the mere presence or absence of disease. Also, it is a matter of common observation that trees of the same age, height, and caliper may display roots that are either of normal form or misshapen and show various stages of

hard gall, soft gall, and hairy root. With the passage of time it has become evident that the statements made above are strongly supported by the behavior of the trees in this test.

RESULTS OF EXPERIMENT AFTER 8 YEARS

After 8 years of growth, the trees began to crowd each other making it necessary to remove most of them. Of the 433 trees planted only 93 were allowed to remain for future observation. The tops of the trees in some groups showed contrasting growth responses which were not common to all varieties. The Wealthy trees, which normally produce large stout roots, when infected with hairy root were the smallest of any group, being 2 to 3 feet shorter than the checks. The McIntosh, which normally forms fibrous feeding roots, showed no such tendency when similarly infected. In the Wealthy and McIntosh varieties the badly galled trees were smaller than the check trees. The Baldwin showed the greatest uniformity in the diseased trees. The check trees also showed considerable variation, the least variable being those which made up the permanent classes.

INCREMENT OF GROWTH

At the outset of this investigation it was recognized that it would be difficult to determine accurately differences in growth because of the inherent variability of the trees tested. Any method of recording differences such as weight of the top, apical growth of the branches, and increase in diameter of the trunk is open to objection and hence such data must be considered as only indicative. Whether or not they have any significance can be determined only when the ultimate results show a preponderance of evidence in favor of one or the other of the types considered. In lieu of any accurate method of measurement the writer selected the one most easily taken, namely, that of increment of growth. Each year the diameter of the trunk of each tree was measured 1 foot above the ground. A summary of the data is given in Table 3. The application of statistical methods to the data shows that in the case of the Baldwin with variable check trees the mean differences in growth are not significant, while with the other two varieties the requirements of significance are fulfilled. The data represent the accumulative effect of numerous variables which can not always be properly evaluated. Some of these factors acting alone may result in a greater ultimate response than that due

TABLE 3.— INCREASE IN THE TRUNK DIAMETER OF NORMAL AND DISEASED APPLE TREES.

DISEASE	DIAMETER IN CM					INCREASE IN CM	NUMBER OF TREES	
	1925	1927	1929	1932	1933		Alive	Dead*
Baldwin								
Check	1.46	2.26	2.95	5.43	6.44	4.98	13	0
Hairy root	1.53	2.18	2.95	4.88	5.74	4.21	28	2
Moderately galled	1.62	2.34	3.14	5.05	5.81	4.19	34	3
Badly galled	1.57	2.30	3.05	4.91	5.76	4.19	32	5
Wealthy								
Check	1.86	2.71	3.56	6.12	7.03	5.17	16	1
Hairy root	1.48	1.96	2.58	4.52	5.43	3.95	32	0
Moderately galled	1.47	2.20	2.93	5.30	6.30	4.83	46	2
Badly galled	1.61	2.20	2.90	4.98	5.92	4.31	41	2
McIntosh								
Check	1.45	2.17	3.10	5.94	7.11	5.66	14	3
Hairy root	1.44	2.39	3.41	6.29	7.44	6.00	27	3
Moderately galled	1.38	1.98	2.90	5.39	6.46	5.08	40	4
Badly galled	1.41	2.04	2.70	4.71	5.81	4.40	34	4

* Not included in determining averages.

to the presence and absence of disease. The two outstanding variables that played the greatest rôle outside the disease factor were: (1) The size, number, and arrangement of the roots; and (2) the number, arrangement, and height of the lower branches. Regardless of these factors the presence of crown gall and hairy root usually reduced the height as well as the increment growth of infected trees.

ROOT DEVELOPMENT

Often when it was impossible to determine the injurious influence of the diseased roots by means of top growth, the examination of the root system dispelled any doubts. The trees were pulled by means of a tractor, and it was observed that the diseased trees were the most readily removed. Wealthy trees infected with hairy root displayed the least resistance to the tractor because some trees had mere bunches of roots, the largest often being no more than 0.5 inch in diameter. Some trees had broken off due to the formation of cross-grained tissue at the place of gall attachment.

As a tree was removed the roots were examined and compared with the original description made at the time of setting. In a few instances the galls could not be found. In most cases the original

galls were still present and sometimes galls were found which were not observed when planting. All galls had increased in size, were of the hard type, and failed to disintegrate. One tree was found on which the gall had disintegrated and collar rot resulted (Fig. 13). Some galls could not be distinguished from callus overgrowths.

SUMMARY OF ROOT OBSERVATIONS

Hedgcock (5) believed that forms of crown gall and hairy root at or near the crown of an apple tree in the orchard have very little effect on the subsequent growth of the tree, provided it has a well-developed root system and is able to throw out roots above such growths; otherwise, a marked stunting effect may follow. The writer's conclusions, based on the trees uprooted after 8 years of growth, are summarized as follows:

1. A tree having a poor root system at the time of setting usually showed a poor root system at the time of its removal.
2. A check tree with a poor root system may show less top growth than a diseased tree with a good root system.

FIG. 8.—A WELL-FORMED ROOT SYSTEM OF A NORMAL BALDWIN AFTER 8 YEARS IN THE ORCHARD.

The trunk diameter increased 2.40 inches (6.12 cm).

3. Some of the galls originally classified as soft turned out to be the hard gall type with well-developed bark and woody tissue. Some galls were smooth, while others were rough and showed the development of hairy root.
4. A tree with a gall at the base of the rootstock so that roots readily form above it, may produce a normal root system and top growth.
5. Galls gradually increase in size and hence a small gall near the crown may later grow to a size sufficient to exert a girdling effect. (Compare Figs. 8, 9, and 11.)
6. The presence at the crown of a gall, an overgrowth, or an encircling root may have a similar girdling effect, inhibit the formation of roots, and thus produce a one-sided root system (Fig. 12).

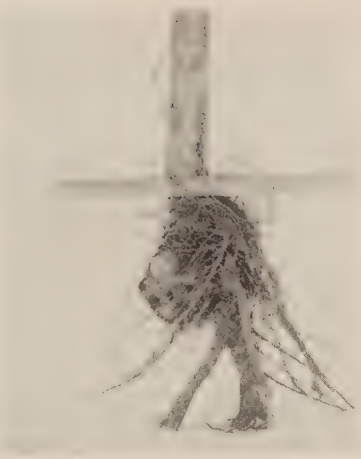

Fig. 9.—The Poor Root System of a Baldwin that Originally Had a 2½-Inch Gall on the Trunk.

Roots easily broken. After 8 years the trunk increased 1.05 inches (2.69 cm).

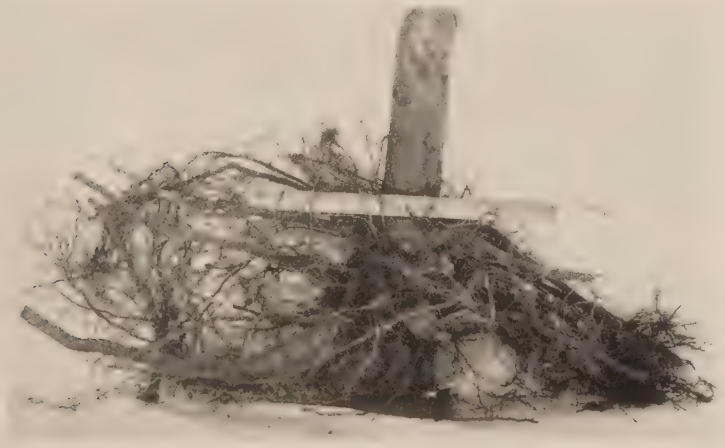

Fig. 10.—The Root System of a Baldwin Infected with Hairy Root. After 8 years the trunk increased 1.49 inches (3.80 cm).

Fig. 11.—A One-sided Root System of Wealthy Induced by the Presence of a Gall.

After 8 years the trunk increased 2.15 inches (5.48 cm).

7. Trees infected with hairy root showed considerable variation and often showed an undersized as well as a one-sided root system. Judging from the top growth a hairy root system appears to be an efficient mechanism for obtaining soil water and solutes (Fig. 10).
8. Some of the McIntosh trees which had been classified by the writer as hairy root apparently possessed the burr knot type of root, since they made an excellent system with numerous fibrous feeding roots (Fig. 14).
9. The predominant feature noted in these uprooted trees was the poor root systems of trees affected with either crown gall or hairy root.

APPLICATION OF RESULTS

FROM THE POINT OF VIEW OF THE ORCHARDIST

The orchardist setting out an apple orchard has before him a long-term project that requires an outlay of considerable capital and labor. To insure the success of this venture, he is entitled to nursery stock that is not handicapped by the presence of root diseases and malformations. Each tree must be considered individually as to whether or not it is fit to have a place in the orchard. One can find considerable variation even among trees that fulfill the horticultural standard as being of definite caliper and height, of fair shape,

branched, and well rooted. From the examination of the nursery stock the orchardist is unable to foretell how the presence of overgrowths, crown gall, or hairy root may influence the future growth of the tree. Since their presence may be injurious, the safest policy is to reject such trees and to consider them as culls. (Fig. 13.) New York fruit growers are fortunate in that most apple nursery trees now grown in this State are on budded stock, hence show no overgrowths and are comparatively free from crown gall.

FIG. 12.—THE POOR ROOT SYSTEM OF A WEALTHY TREE INDUCED BY A GALL AND BY THE GIRDLING OF THE ROOT ARISING AT THE RIGHT AND ENCIRCLING THE TRUNK.

The root, which was incorporated in the gall, has separated on drying of the gall tissue. After 8 years the trunk increased 1.89 inches (4.80 cm).

FIG. 13.—THE POOR ROOT SYSTEM OF A WEALTHY TREE SHOWING A 5-INCH GALL AND THE COLLAR ROT RESULTING FROM SECONDARY INFECTION.

The upper limits of the canker have been outlined with string. After 8 years the trunk increased 1.95 inches (4.95 cm).

A well-formed root system is the greatest assurance of having a vigorous-growing tree. Trees having a well-formed root system with numerous feeding rootlets either thruout or on the uppermost horizontal roots should not be mistaken for hairy root. The latter tends to produce fleshy roots which are seldom associated with good root formation.

FIG. 14.—ROOT SYSTEM OF McINTOSH THAT ORIGINALLY HAD A GALL 7/8 INCH IN SIZE WHICH HAS INCREASED TO A GALL 3 BY 6 INCHES.

The roots are of the burr knot type. After 8 years the trunk has increased 2.46 inches (6.23 cm).

FROM THE POINT OF VIEW OF THE NURSERYMAN

In attempting to produce the best possible apple trees, the nurseryman is often a victim of circumstances. In New York, he has learned by costly experience that grafted stock has a high percentage of trees showing either overgrowths or crown gall which would not pass the inspection service. In contrast, budded stock growing alongside the grafted blocks may show but a fraction of 1 per cent of crown gall. Nurserymen have observed that grafted stock grown on any soil may be infected with gall and have concluded that the organism is present in all soils. However, the lack of crown gall on budded stock indicates that some New York soils are not infected by the crown gall organism. Budded apple stock grown in fields following infected peaches, roses, raspberries, etc., may be so severely infected as to cause the entire block to be ruined for sale. It is believed that the avoidance of crown gall on the seedling stock is

the greatest means of preventing the dissemination of the organism in nursery greenhouses and fields.

The views of pathologists, nurserymen, and nursery inspectors are in agreement in considering as culls those trees whose trunk or main rootstock is infected with crown gall or hairy root. Representatives of these groups in the 1923 symposium considered trees like those shown in Exhibit No. 1 (Fig. 15) as undesirable for orchard pur-

Fig. 15.—A Nurseryman's View of the Types of Trees that Should be Avoided.

"They do not reflect good craftsmanship, they are culls on general principles, they are freaks and deformities and their place is on the cull pile." (See Chase, 2.).

poses (2). Since the writer found no evidence that the infection is systemic on well-established trees, it seems unwise to destroy a vigorous, well-branched tree with a good root system but with a gall present on a lateral branch. The removal of a localized gall on a lateral branch by pruning is permissible, provided its removal does not unduly mutilate the root system. This pruning should be per-

formed by the nurseryman prior to the sale of the tree. The removal of gall tissue by cutting it flush with the surface of the rootstock does not remove the infection. Such trees are discarded by the inspection service just as tho the gall were present.

FROM THE POINT OF VIEW OF THE NURSERY INSPECTOR

In the light of the present investigation there appears to be no change in the general impressions concerning crown gall and hairy root, but it seems worth while to attempt to clarify our views so as to establish uniformity of inspection and the elimination of controversy from this problem. The object of the inspection of apple nursery stock should not be to establish an economic quarantine; its purpose should be to prevent the sale of diseased stock which may prove injurious and thus protect the orchardist, as well as the nurseryman, from subsequent losses.

The regulations governing the inspection of apple nursery stock are quite variable in different states and have resulted in considerable controversy. This variability may be due either to differences in instructions or to their interpretation by inspectors having different experiences and points of view. When the infectious nature of the crown gall disease was first discovered, inspectors were too zealous in their duties and tended to burn the entire shipment when a given number of diseased trees were discovered. Such uncalled for destruction of trees was based on the false assumption that, if a few trees were diseased, then all trees in the shipment might be infected. More recently, there has been a tendency to go to the other extreme and to be too lenient. The nurserymen gained toleration because of a previous lack of knowledge which, in specific cases, raised a doubt as to whether the tree was suffering from an infectious disease or whether other factors might be involved, such as callus overgrowths, burr knot, variability of the formation of fibrous roots in different soils and upon different varieties. The experienced inspector need not resort to isolation of the organism and other hair-splitting methods in order to judge whether or not a tree is diseased; he can readily distinguish at a glance the various types of diseases involved.

It is hoped that the present investigation may promote the just understanding necessary for the uniform inspection of apple nursery stock. The following points may serve as a guide in establishing uniformity:

1. An inspection of the dug trees is the only known method for determining accurately the presence of the various diseases on the roots and a blanket certificate, as issued by some states, has little value when based on the examination of the growing stock in the field.
2. When healthy and diseased trees are found in the same consignment, the healthy trees should not be rejected. In some states the nurserymen are allowed a tolerance of 5 per cent of diseased trees and hence regularly include that amount in their shipment. On entry into this State, such diseased trees are rejected and this procedure has led to some confusion.
3. An inspector should reject every tree offered for sale showing distinct signs of crown gall. At the time of inspection it is impossible to predict to what extent a gall on the trunk may continue its growth and ultimately injure the tree. Hence, the size of the gall and the type and degree of infection observed on the tree should not influence the judgment of the inspector.
4. Where an occasional galled or hairy-rooted tree is found, it can readily be removed by the inspector. Where an abundance of galled trees have been included in the lot, the shipper should be called upon to compensate for the extra labor involved by neglecting to sort the stock properly prior to sale.
5. Trees should be rejected where the galled tissue has been pared away from the trunk and rootstock, since such a procedure does not remove all of the infected tissue.
6. Galls on the lateral roots should also be rejected, even tho it were possible for the orchardist to prune away the galls before setting the tree. It must be assumed that the ultimate grower may not know the significance of such galls and hence must be given the benefit of any doubt by the rejection of the tree.
7. The crown gall infection appears to be localized and no evidence has been found that the infection is systemic on well-established nursery stock. The pruning of a lateral root so as to remove a gall is permissible and should be performed by the nurseryman prior to its sale. Where the roots have been excessively pruned so as to spoil their arrangement, shape, and number, the tree automatically enters into the cull class.
8. Seedlings entering New York should be carefully inspected since the presence of the crown gall on such stock may be a means of disseminating the organism to nursery fields heretofore free from disease.
9. It is often impossible to distinguish the intergradations of callus overgrowths and crown gall. Since the overgrowths may affect the tree in a manner similar to crown gall in producing a misshapen root system, it may be advisable to reject trees showing excessive malformations. The problem of overgrowths on New York-grown stock is not of importance since most of the trees of this State are budded.

10. Due to a mixed infection, one may find intergradations between crown gall and hairy root.
11. Hairy root can be distinguished by the production of fleshy roots which should not be confused with the fibrous feeding roots of normal trees.
12. While examining standard trees, the inspector must be guided by the general appearance of the root system. If a tree shows a large broom effect of fleshy roots and is devoid of normal stout roots, it can readily be rejected as diseased. Where a tree displays a well-formed, normal root system, the presence of a tuft of semi-fleshy roots on the trunk does not appear to be sufficient reason for condemning the tree. The removal of such tufts by the nurseryman appears to be a permissible procedure.
13. To produce dwarf trees, Paradise and Doucin stocks are used. Because of a burr knot characteristic, these stocks may normally produce an excessive amount of semi-fleshy roots which resemble a severe case of hairy root.
14. In a population of standard trees the burr knot root type may also be found without causing a dwarfing of the tree. It is associated with a well-developed root system which often is better than the normal in the size and number of the roots. The tufts of fibrous feeding roots arising uniformly from slight swellings on the lateral roots should not be mistaken for the infectious hairy root.
15. The inspectors must be acquainted with variation in the root response when trees are grown under various soil conditions. More fibrous feeding roots are found where the trees are grown in loam soil rich in organic matter than on heavy clay soil. Both types may be found on the same field and when found mixed in the bundles, the fibrous roots by contrast are often mistaken for the infectious hairy root. Under similar conditions the Yellow Transparent variety showed the greatest tendency toward fibrous root formation of any variety encountered.

CONCLUSIONS

On the nursery stock and after 8 years' observations on the growth in the orchard, it was evident that neither the height of the tree nor its caliper were always an accurate means of determining the injurious influence of crown gall and hairy root. The number, size, and location of galls may be growth inhibiting factors. Other variables, such as branch and root pruning, shape and distribution of the root system, etc., may exert a greater influence on the top growth of an individual tree than the mere presence or absence of root infection. It was found that the tree having a good root system

at the time it was set tended to produce the best top growth. No matter what the causal agent may be, the presence on the trunk of either crown gall or hairy root tends to produce an abnormal root system.

In this and other similar tests the final results observed depended upon the type of material selected at the outset of the experiment. Whenever a random lot of normal and diseased trees has been compared in an orchard, the healthy trees generally have produced the best average growth. By the proper choice of normal trees it is possible to select a group with a good root system that would make a better top growth than another group having a less developed root system. Likewise, by proper selection of galled trees one could show, if he so desired, that the presence of the gall was either beneficial, non-injurious, injurious, or even that it killed the trees. For instance, a tree with a gall at the base of the rootstock and a well-developed root system above it, may in an actual test show a better top growth than a disease-free tree with a less developed root system. The presence of the gall at the crown invariably tended to have a girdling effect and inhibited the formation of roots on the infected side of the tree. It is too early to determine the ability of the trees having a one-sided root system to withstand heavy winds when laden with fruit.

At the time the tree is set it is impossible for the orchardist to foretell how the various root infections may influence the future growth of the tree. Hence, it is advisable for him not to plant infected trees. The nurseryman should consider as culls all trees showing crown gall and hairy root. He should be allowed to prune lateral roots on which galls are present, provided their removal does not mutilate the root system so as to make the tree a cull.

Neither a relaxation nor a modification of the present inspection regulations is warranted for this State. An acquaintance with the signs and symptoms of the infectious diseases, as well as the variations of normal rootstock development of different varieties and on various soils, appears to be the greatest means of establishing uniformity of inspection between the various states and provinces. The proper understanding of the difficulties encountered in the production of a normal apple tree will lead to an increase in toleration and the elimination of controversy between orchardist, nurseryman, and nursery inspector.

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